Topics for Today:

- Announcements
  - Term Project outlines (i.e. Table of Contents + List of references, should have feedback shortly if not already.
  - Software: online students - apply for ATP/ATPDraw license, verify licensing when you receive it by e-mail, and we will mail you the install CD.
  - ASPEN software - arranging to run off of MTU server via internet.
  - Office: EERC 614. Phone: 906.487.2857
  - Recommended problems & all solutions: Ch.7 solns posted.

- Chapter 7 - Network Equations, Admittance Approaches
  - How's your linear algebra? Time to make use of it...
  - Basic strategy for building up [Y] for whole network
  - Quick recap of xfmrs and lines.
  - Generators
  - Example of building [Y] for 4-bus system.
  - Network Reduction (Kron Reduction)
  - Solution of matrix equations (system of linear equations)
  - Upcoming homework - intro to Matlab, matrices, equations.
\[ R \quad \frac{X}{0.08 \text{pu.}} \quad \frac{B_c}{0.105 \text{pu.}} \quad ? \]

... 8 MVAR total line charging @ rated voltage.

\[ Q = \frac{V^2}{X_c} = V^2 B_c \]
\[ = (1.0)^2 B_c = 0.04 \text{ p.u.} \]
\[ \Rightarrow B_c = 0.04 \text{ p.u.} \]
3-Winding XFMRs

See Section 2.8 in text.

NAMEPLATE EX.
(See last page).

EACH LEG OF CORE
Refer to section 2.8 in text...

\[ Z_{ps} = Z_p + Z_s \]
\[ Z_{ps} = Z_p + Z_T \]
\[ Z_{ps} = Z_s + Z_T \]
\[ \Rightarrow \]
\[ Z_p \]
\[ Z_s \]
\[ Z_T \]

Fictitious node, \[ F \] is 4x4.

Per-Phase "Star" equiv
- All transfer impedances are positive. OK for most S.C. and load-flow calcs.
- Neg \( Z_s \) can cause trouble in some computer simulations.

Can convert, \( Y \rightarrow \Delta \)

When building \[ [Y] \] for system, be aware!
- \( Z_s \) is often negative, but \( Z_{ps} = Z_p + Z_s \) is always positive.
- Node in star equivalent does not physically exist.
CAUTION:
DO NOT ATTEMPT TO HANDLE, INSTALL, USE OR SERVICE THIS TRANSFORMER BEFORE READING INSTRUCTION BOOK XLL7952-12. TO DO SO MAY LEAD TO BODILY INJURY OR PROPERTY DAMAGE OR BOTH.
**T-Lines**

Example:
Build [4].

\[ R_t = \omega C \]
\[ Y = jB_e \]

Copi implied that \( \frac{B_e}{2} = j0.05 \text{ pu} \) \( \Rightarrow \) \( 2X_e = -j20 \text{ pu} \)

\( Z_{sc} = 0.08 + j.2 \text{ pu} \)

\( Y_{sc} = \frac{1}{2Z_{sc}} \)

\[ 4.64 \angle -68.2^\circ \text{ p.u.} \]

Add a load.
What happens if we attach a load at Bus 2?

Load \( S \) is given for \( V = 1.0 \text{ p.u.} \), then we can approximate \( Z_{\text{LOAD}} \) and \( Y_{\text{LOAD}} \).
\[ Y_{\text{load}} = 1.0 - j0.5 \text{ p.u.} \]

**How to add effect into \([Y]\)?**

\[
[Y] = \begin{bmatrix}
4.596 \; 1-67.97^\circ & 4.64 \; 111.8^\circ \\
4.64 \; 111.8^\circ & 5.48 \; 60.22^\circ
\end{bmatrix}
\]

**Note:** Since load is connected to Bus 2 (Bus 2 - Gnd) then only \( y_{zz} \) is affected.

\[ y_{zz} \text{ (new)} = y_{zz} \text{ (old)} + y_{\text{load}} \]
where interc.

\[ I_s = \frac{E_s}{Z_a} \quad \text{and} \quad Y_a = \frac{1}{Z_a} \quad (7.3) \]

![Diagram](image)

**FIGURE 7.1**  
Circuits illustrating the equivalence of sources when \( I_s = E_s/Z_a \) and \( Y_a = 1/Z_a \).
Effect of adding 3-wdg xfmr:

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<thead>
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<tr>
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Note: Above is for Δ-egvin. If using star-egvin, must also add star-point as a new bus.
FIGURE 7.3
Single-line diagram of the four-bus system of Example 7.1. Reference node is not shown.

FIGURE 7.4
Reactance diagram for Fig. 7.3. Node 0 is reference, reactances and voltages are in per unit.

admittance matrix for each of the network branches and then write the nodal
\[ I_N = \frac{V_{TH}}{Z_{TH}} \]

\[ I_m = V_{TH} Y_n \]

\[ [Z] = [Y]^{-1} \]

**Figure 7.5**

Per-unit admittance diagram for Fig. 7.4 with current sources replacing voltage sources. Each letter a to g corresponds to the subscripts of branch voltages and currents.

(7.9) applies to each of the other five branches. By setting \( m \) and \( n \) in equations equal to the node numbers at the ends of the individual branches of Fig. 7.5, we obtain

\[
\begin{align*}
&\begin{bmatrix}
1 & -1 \\
-1 & 1 \\
1 & -1 \\
-1 & 1
\end{bmatrix} Y_e \\
&\begin{bmatrix}
1 & -1 \\
-1 & 1 \\
1 & -1 \\
-1 & 1
\end{bmatrix} Y_e
\end{align*}
\]

The order in which the labels are assigned is not important here, provided columns and rows follow the same order. However, for consistency with sections let us assign the node numbers in the directions of the branch currents of Fig. 7.5, which also shows the numerical values of the admittances. Combining those elements of the above matrices having identical row and column labels gives:

\[
\begin{bmatrix}
(Y_e + Y_d + Y_f) & -Y_e & -Y_c & -Y_f \\
-Y_e & (Y_b + Y_e + Y_c) & -Y_b & -Y_e \\
-Y_c & -Y_b & (Y_a + Y_b + Y_c) & 0 \\
-Y_f & -Y_e & 0 & (Y_e + Y_f +...) \\
\end{bmatrix}
\]
[Z_{bus}]

- Hard to construct/modify

[ Y_{bus}]

- Easy to use for S/C, or other S.S. Go-Hze (or 50Hz) calcs.

Easy to get or modify in its use for S.C. studies.

Ex: Fig 7.5 in text

\[
\begin{bmatrix}
-14.5 \\
8 \\
-17 \\
8 \\
-5
\end{bmatrix}
\begin{bmatrix}
4 \\
5 \\
0 \\
8.8 \\
0 \\
-8.3
\end{bmatrix}
\]

Checks w/ p. 245
Modification is easy:
ex: Remove Line 2-3: \((-j4)\)

\[
\begin{bmatrix}
-14.5 & 8 & 4 & 2.5 \\
8 & -13 & 0 & 5 \\
4 & 0 & -4.8 & 0 \\
2.5 & -5 & 0 & -8.3
\end{bmatrix}
\]

\([Y_{bus}]\) is **SPARSE** in general.

Typical "grid" system being analyzed will have 100's or 1000's of buses.

For \(y_{12} = 0\), no line or xfar from 1-2.

\(y_{21} = 0\)
Typically, only 2-5 buses are connected to a given. Most off-diagonal entries of $[Y]$ are 0. When many entries of a matrix are 0, it's a sparse matrix.

- Don't have to store zero values.
- Single-precision complex values, \( \text{HHHH} \) - 8 bytes.

For 10,000 bus system:
\[ \Rightarrow 800 \text{ MB of RAM}. \]

Use linked-list storage, only store the non-zero values.
If each bus is connected to 4 others, then each row has 5 entries.

\[ \Rightarrow \text{50,000 non-zero entries} \]

Only 400 KB needed.

**Import:** \([Z] = [Y]^{-1}\) is a **full** matrix.

Must use factorization methods to obtain desired entries in \([Z] \Rightarrow \text{can find}\)

\[
Z = \begin{bmatrix}
\vdots \\
\vdots \\
\hline
\vdots \\
\end{bmatrix}
\]